

### EXHIBIT 3

## ANALYSIS OF MARKET QUALITY IMPACT OF P.M.-SETTLED INDEX OPTIONS

### I. Background & Research Questions

The analysis aims to evaluate the impact on market quality in connection with Cboe Exchange, Inc.'s (the "Exchange" or "Cboe Options") and certain of its affiliates' listing of P.M.-settled broad-based index options.

### II. Methodology

The study followed the 'difference-in-difference' approach ("DnD") to compare the values of key market quality indicators before-and-after the introduction of Tuesday expirations and Thursday expirations for SPX Weekly ("SPXW") options, which were launched on April 18, 2022 and May 11, 2022 respectively. DnD is a commonly used quasi-experimental technique to estimate causal inference from a nonequivalence control group. It first involves identifying a 'treatment group' and a group of non-treated subjects as 'control group'. In this case, the existing product of SPX Weekly options with Monday/Wednesday/Friday ("M/W/F") expirations was the treatment group and SPY options with Monday/Wednesday/Friday expirations was the control group. Although the Exchange considered using the E-mini Weekly options as a control group as they are more similarly situated to SPXW options, CME also began listing Tuesday and Thursday expirations, therefore the Exchange does not believe that E-mini Weekly options can be used as a control group for this study. The Exchange notes that the use of SPY options presents certain limitations as a result of systematic differences between SPXW options and SPY options. For example: SPY options pay a dividend every quarter whereas SPX options do not; the minimum tick size requirements differ; and SPY options are American-style and physically settled, whereas SPXW options are European-style and cash-settled.

The study calculated the difference in market quality indicators before and after the ‘treatment’ (the introduction of SPXW Tuesday/Thursday expirations in this case) on each group. The impact could therefore be assessed by comparing the pre/post changes in the SPXW M/W/F expirations series with those from the SPY M/W/F expirations series. In addition, the parallel trend assumption should be met to ensure the internal validity of DnD model, which requires the difference between the treatment and control group to be constant over time before the intervention.

In addition, the Exchange does not believe that SPX AM options can be used as a treatment group with the SPY options as the control group. First, one of the essences of the DnD framework is to pair the treatment group with the comparable control group. Since there’s only one set of series available for SPY to match with SPX, including SPX in the model will introduce double-counting SPY. Second, SPY might not be a good comparison to SPX given their different settlement schedules. For the contract expiring on the same day, SPY options always have a longer day to expiration than SPX options. The Exchange also conducted a correlation test comparing SPX AM vs SPY, from which a weaker correlation in the key market quality indicators was observed. Therefore, adding SPX AM options to the analysis is not recommended due to the intrinsic differences between the products.

### **Key Market Quality Indicator of Interest**

The Bid-Ask Spread (“Spread”) was used as one of the key indicators of market quality in the analysis. Specifically, daily time-weighted Spread on the Exchange during Regular Trading Hours (“RTH”) was calculated for SPXW M/W/F series, and daily time-weighted Spread of the NBBO will be calculated for SPY M/W/F series. Since an SPX option is about 10

times the value of an SPY option, the Spread of SPY options was adjusted by x10 to scale it with the Spread of SPXW options.

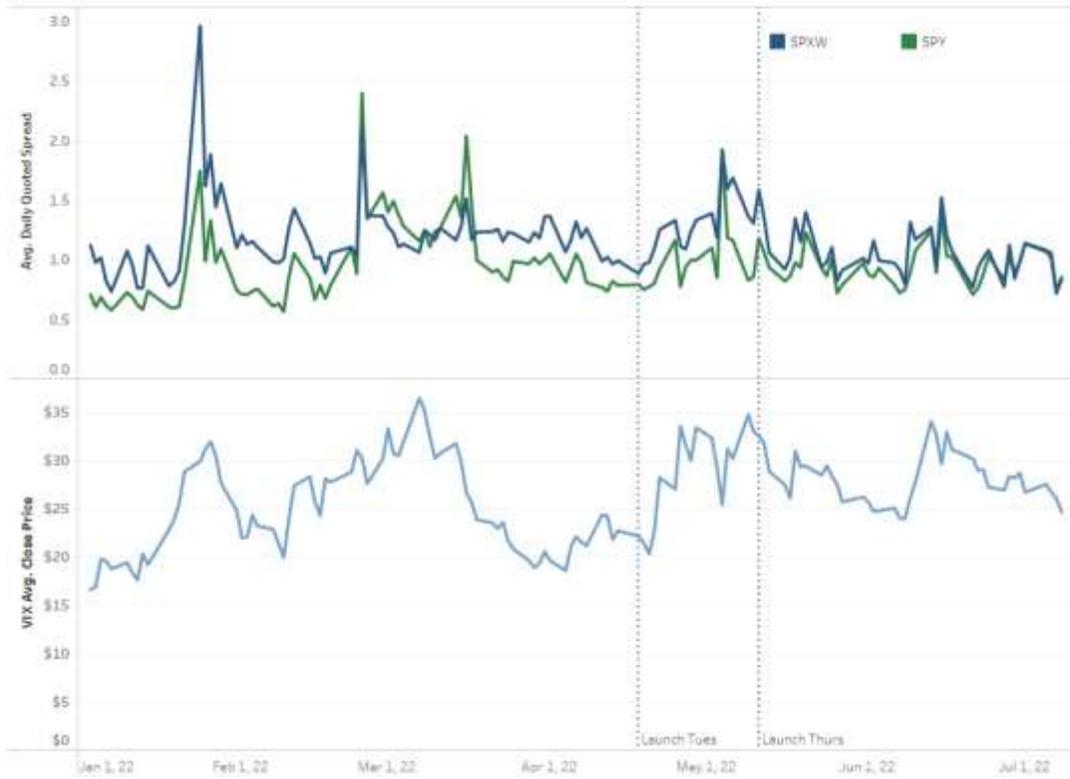
The Effective Spread for simple trades was used as another indicator of market quality, where the Effective Spread measures the twice of the amount for the absolute value of an order execution to the midpoint of the national best bid and national best offer at the time of execution. The volume-weight average daily Effective Spread for the order executions on the Cboe Exchanges was calculated for both SPXW M/W/F series and SPY M/W/F series. The Effective Spread of SPY options was adjusted by x10 to scale it with the Effective Spread of SPXW options for the same reason mentioned above. Below shows the formula for Effective Spread:

$$\text{Effective Spread} = \text{Abs} \left( \text{Order Execution Price} - \frac{(\text{National Best Bid} + \text{National Best Offer})}{2} \right) \times 2$$

### **Time Range**

Data was compared between the pre-intervention period and the post-intervention period. The post-intervention data was collected for the time range from May 11, 2022 to July 10, 2022 (two calendar months following the introduction of Thursdays expirations), and the pre-intervention time range from January 3, 2022 to March 4, 2022 (two calendar months). The Exchange believes the selection of pre-intervention time range has similar market conditions to the post-intervention period that the two time periods share comparable market volatility levels

**Table 1: SPXW & SPY Quoted Spread Trend**



**Table 2: SPXW & SPY Effective Spread Trend**

Note: Tables 1 and 2 only show paired SPXW & SPY series with the strike price +/- 3% to the spot price and DTE within 27 days.

### Grouping of Samples

In order to make fair comparisons between the symbols possessing similar characteristics, the analysis matched each SPXW and SPY pair by the same moneyness and days to expirations (“DTE”) group. For example, an in-the-money SPXW call option that expired on April 28, 2022 was compared to the matching SPY call option expiring on the same Expiration Day with the same (notionally adjusted) strike price as the SPXW option; the series of contracts having similar moneyness to the end of day index level of the underlying and the DTE of the trading day will be grouped together. Fixing moneyness and DTE ensures the pairs in each trade day have similar characteristics. The analysis included all SPXW and SPY paired contracts with the strike price

+/- 3% to the spot price and DTE within 27 days. Tables 3 through 6 provide the summary information of the matched pair data by DTE and moneyness group before and after the intervention.

**Table 3: SPXW & SPY Series Quoted Spread Summary Stats (All ITM contracts)**

Dte (group)	Trade Dat..	ITM 1-3%				ITM 0-1%			
		Avg. Daily Bid-Ask Spread		Number of Paired Symbols		Avg. Daily Bid-Ask Spread		Number of Paired Symbols	
		SPXW	SPY	SPXW	SPY	SPXW	SPY	SPXW	SPY
0-3	Pre	1.904	1.152	1,209	1,209	0.798	0.480	559	559
	Post	1.804	0.940	1,280	1,280	0.641	0.450	617	617
4-7	Pre	2.421	0.743	1,073	1,073	0.753	0.361	528	528
	Post	1.894	0.772	1,123	1,123	0.536	0.363	559	559
8-11	Pre	1.802	0.769	1,056	1,056	0.638	0.428	516	516
	Post	1.411	0.885	1,096	1,096	0.510	0.425	550	550
12-15	Pre	1.564	0.751	1,141	1,141	0.670	0.453	560	560
	Post	1.204	0.919	1,143	1,143	0.535	0.454	606	606
16-19	Pre	1.376	0.725	1,018	1,018	0.674	0.460	505	505
	Post	0.968	1.018	974	974	0.533	0.438	512	512
20-23	Pre	1.412	0.896	1,145	1,145	0.753	0.535	575	575
	Post	0.890	1.150	1,172	1,172	0.577	0.504	620	620
24-27	Pre	1.659	1.185	873	873	0.868	0.672	454	454
	Post	0.875	1.242	955	955	0.660	0.623	526	526

Note: Showing normalized SPY quoted spread (multiplied by 10)

**Table 4: SPXW & SPY Series Quoted Spread Summary Stats (All OTM contracts)**

Dte (group)	Trade Dat..	OTM 0-1%				OTM 1-3%			
		Avg. Daily Bid-Ask Spread		Number of Paired Symbols		Avg. Daily Bid-Ask Spread		Number of Paired Symbols	
		SPXW	SPY	SPXW	SPY	SPXW	SPY	SPXW	SPY
0-3	Pre	0.325	0.168	525	525	0.190	0.111	1,020	1,020
	Post	0.209	0.131	578	578	0.122	0.101	968	968
4-7	Pre	0.461	0.215	522	522	0.338	0.150	1,067	1,067
	Post	0.320	0.153	557	557	0.209	0.111	1,112	1,112
8-11	Pre	0.479	0.303	518	518	0.392	0.225	1,053	1,053
	Post	0.352	0.199	550	550	0.265	0.129	1,094	1,094
12-15	Pre	0.537	0.349	560	560	0.451	0.274	1,141	1,141
	Post	0.393	0.244	606	606	0.319	0.157	1,143	1,143
16-19	Pre	0.558	0.373	505	505	0.464	0.298	1,018	1,018
	Post	0.409	0.260	512	512	0.340	0.171	974	974
20-23	Pre	0.610	0.423	575	575	0.506	0.345	1,144	1,144
	Post	0.457	0.305	620	620	0.388	0.205	1,172	1,172
24-27	Pre	0.704	0.531	454	454	0.582	0.430	874	874
	Post	0.530	0.400	526	526	0.439	0.271	955	955

Note: Showing normalized SPY quoted spread (multiplied by 10)

**Table 5: SPXW & SPY Series Effective Spread Summary Stats (All ITM contracts)**

Dte (group)	Trading Dt..	ITM 1-3%				ITM 0-1%			
		Avg. Daily Effective Spread		Number of Paired Symbols		Avg. Daily Effective Spread		Number of Paired Symbols	
		SPXW	SPY	SPXW	SPY	SPXW	SPY	SPXW	SPY
0-3	Pre	0.345	0.257	905	905	0.246	0.182	627	627
	Post	0.392	0.312	825	825	0.242	0.189	521	521
4-7	Pre	0.473	0.333	633	633	0.370	0.238	515	515
	Post	0.434	0.354	565	565	0.348	0.217	417	417
8-11	Pre	0.482	0.426	473	473	0.377	0.264	475	475
	Post	0.469	0.463	486	486	0.394	0.268	372	372
12-15	Pre	0.611	0.552	410	410	0.533	0.339	398	398
	Post	0.589	0.424	339	339	0.447	0.307	327	327
16-19	Pre	0.596	0.481	345	345	0.468	0.303	341	341
	Post	0.949	0.436	218	218	0.490	0.299	231	231
20-23	Pre	0.788	0.656	297	297	0.500	0.523	328	328
	Post	0.532	0.471	244	244	0.482	0.303	281	281
24-27	Pre	0.744	0.585	172	172	0.523	0.386	228	228
	Post	0.790	0.450	132	132	0.710	0.402	164	164

Note: Showing normalized SPY effective spread (multiplied by 10)

**Table 6: SPXW & SPY Series Effective Spread Summary Stats (All OTM contracts)**

Dte (group)	Trading Dt..	OTM 0-1%				OTM 1-3%			
		Avg. Daily Effective Spread		Number of Paired Symbols		Avg. Daily Effective Spread		Number of Paired Symbols	
		SPXW	SPY	SPXW	SPY	SPXW	SPY	SPXW	SPY
0-3	Pre	0.171	0.154	631	631	0.144	0.138	1,231	1,231
	Post	0.168	0.150	522	522	0.123	0.129	1,057	1,057
4-7	Pre	0.318	0.198	540	540	0.271	0.167	1,086	1,086
	Post	0.311	0.195	425	425	0.247	0.154	875	875
8-11	Pre	0.347	0.207	516	516	0.296	0.185	1,011	1,011
	Post	0.354	0.230	395	395	0.325	0.185	762	762
12-15	Pre	0.451	0.253	446	446	0.332	0.221	869	869
	Post	0.398	0.268	377	377	0.318	0.227	678	678
16-19	Pre	0.445	0.254	367	367	0.481	0.207	755	755
	Post	0.531	0.264	259	259	0.361	0.217	469	469
20-23	Pre	0.534	0.330	384	384	0.398	0.264	692	692
	Post	0.433	0.273	311	311	0.381	0.221	550	550
24-27	Pre	0.411	0.408	276	276	0.476	0.324	481	481
	Post	0.659	0.296	188	188	0.475	0.258	318	318

Note: Showing normalized SPY effective spread (multiplied by 10)

### The DnD Regression Model

A DnD regression model can be expressed as:

$$Y = \beta_0 + \beta_1 \text{ Intervention} + \beta_2 \text{ Time} + \beta_3 \text{ Intervention} \times \text{Time} + \varepsilon$$

This is a linear regression model.  $Y$  is the observed value of the targeting market quality indicator before and after treatment.  $\beta_0$  is the intercept of regression, which is the baseline average for the control group before treatment.

*Intervention* is a dummy variable (0 or 1) that refers to whether an observation is in the control group or treatment group. Its coefficient ( $\beta_1$ ) measures the differences between treatment and control group pre-intervention.

*Time* is a dummy variable (0 or 1) that specifies the time periods (pre or post treatment) for each observation. Its coefficient ( $\beta_2$ ) measures the time trend in control group.

*Intervention*  $\times$  *Time* is an interactive term that takes the multiplication of *Time* and *Intervention* variable for each observation in the regression model. Its coefficient ( $\beta_3$ ) will be the

difference in the changes for the treatment group over time due to the introduction of Tuesday/Thursday expirations of the market quality indicator of interest. For example, a positive and statistically significant coefficient for bid-ask spread will suggest a wider quoted spread, or a negative impact on market quality for SPXW options, and vice versa. Finally, the  $\varepsilon$  is the error term that represents the effects that the model was not able to capture.

### **III. Correlation Analysis**

The Exchange conducted two sets of correlation tests regarding bid-ask spread and effective spread between the paired SPXW and SPY series by their moneyness and DTE group during the pre-intervention period. A correlation test measures the strength and direction of association between the treatment and control group, and the values of correlation coefficient range between  $-1$  and  $+1$ . The relationship between the two variables is considered as a strong correlation when the coefficient equals or greater than  $0.75$ . Table 7 and Table 8 show the correlation coefficients for bid-ask spread and effective spread, respectively. For example, a coefficient of  $0.83$  in 0-3 DTE and ITM 1-3% call options group in bid-ask spread suggests a positive and strong correlation between the paired SPXW and SPY series in that group. In other words, these series tend to move in the same direction and in a similar fashion during the pre-intervention period.

In general, the Exchange observed strong positive correlations between the paired SPXW and SPY series in both market quality indicators during the pre-intervention period. Specifically, the correlations generally get stronger when the series have a shorter DTE and are closer to at-the-money. The results help support the parallel trend assumption under the DnD framework, that the treatment and control group move in similar trends before the intervention. Groups with

strong correlation (coefficient  $\geq 0.75$ ) will be selected to perform DnD regressions as those are the most comparable pairs for the DnD analysis.

**Table 7: Bid-Ask Spreads Correlation Results**

	Money/DTE	0-3	4-7	8-11	12-15	16-19	20-23	24-27
	<b>ITM 1-3%</b>	0.83	0.75	0.74	0.56	0.43	0.28	0.51
Call	<b>ITM 0-1%</b>	0.96	0.90	0.91	0.89	0.84	0.76	0.71
Options	<b>OTM 0-1%</b>	0.96	0.92	0.89	0.92	0.84	0.74	0.84
	<b>OTM 1-3%</b>	0.97	0.94	0.93	0.94	0.93	0.75	0.89
	<b>ITM 1-3%</b>	0.70	0.62	0.80	0.71	0.55	0.51	0.40
Put	<b>ITM 0-1%</b>	0.86	0.88	0.89	0.86	0.80	0.69	0.69
Options	<b>OTM 0-1%</b>	0.91	0.88	0.94	0.93	0.96	0.91	0.84
	<b>OTM 1-3%</b>	0.95	0.96	0.98	0.96	0.98	0.91	0.85

**Table 8: Effective Spreads Correlation Results**

	Money/DTE	0-3	4-7	8-11	12-15	16-19	20-23	24-27
	<b>ITM 1-3%</b>	0.56	0.67	0.43	(0.08)	0.46	0.77	0.19
Call	<b>ITM 0-1%</b>	0.93	0.66	0.83	0.29	0.64	0.56	0.66
Options	<b>OTM 0-1%</b>	0.85	0.90	0.72	0.77	0.61	0.39	0.31
	<b>OTM 1-3%</b>	0.89	0.85	0.76	0.77	0.77	0.55	0.09
	<b>ITM 1-3%</b>	0.63	0.57	0.68	0.57	0.46	0.12	0.35
Put	<b>ITM 0-1%</b>	0.78	0.88	0.79	0.28	0.50	0.55	(0.10)
Options	<b>OTM 0-1%</b>	0.76	0.77	0.80	0.60	0.60	0.78	0.06

	<b>OTM 1-3%</b>	0.85	0.84	0.90	0.60	0.87	0.65	0.54
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#### IV. Regression Results

Tables 9 and 10 show the estimated coefficients for the DnD regressions for the market quality indicators between the treatment and control group, together with the p-value in parentheses. The p-value can be used to measure the statistical significance of the coefficient—the confidence that the true value of the coefficient is different than zero. A p-value of 0.1 or lower is considered statistically significant under the regression model. As stated, the regression results only include the groups with strong correlations (with the coefficient  $\geq 0.75$ ) during pre-intervention period. As shown in Table 9 below, the regression results are accompanied by a set of asterisks indicating the associated level of significance: \* = 10%, \*\* = 5%, and \*\*\* = 1%.

**Table 9: Bid-Ask Spread Regression Results**

Moneyness/DTE		<b>0-3</b>	<b>4-7</b>	<b>8-11</b>	<b>12-15</b>	<b>16-19</b>	<b>20-23</b>	<b>24-27</b>
<b>Call Options</b>	<b>ITM 1-3%</b>	-						
		0.65***						
		(0.000)						
	<b>ITM 0-1%</b>	-0.17**	-0.10	0.01	0.08	0.02	0.18***	
		(0.020)	(0.153)	(0.856)	(0.155)	(0.681)	(0.001)	
	<b>OTM 0-1%</b>	-0.02	0.04	-0.02	-0.02	-0.04		0.12**
		(0.534)	(0.236)	(0.415)	(0.494)	(0.310)		(0.025)
	<b>OTM 1-3%</b>	0.00	0.02**	0.00	-0.02	-0.04*		0.08***
		(0.665)	(0.032)	(0.875)	(0.310)	(0.090)		(0.008)

	<b>ITM 1-3%</b>			-				
				0.94***				
				(0.000)				
<b>Put Options</b>	<b>ITM 0-1%</b>	-0.11	-0.10	-0.01	-	0.09		
		(0.178)	(0.160)	(0.832)	0.13**	(0.157)		
						(0.013)		
	<b>OTM 0-1%</b>	-0.02	0.03	0.05*	-0.01	0.00	0.07*	0.18***
		(0.562)	(0.206)	(0.087)	(0.804)	(0.976)	(0.088)	(0.000)
	<b>OTM 1-3%</b>	0.00	0.03**	0.01	-0.03	-	0.02	0.08***
		(0.671)	(0.011)	(0.611)	(0.192)	0.06**	(0.476)	(0.004)
						(0.043)		

**Table 10: Effective Spread Regression Results**

	Moneyiness/DTE	<b>0-3</b>	<b>4-7</b>	<b>8-11</b>	<b>12-15</b>	<b>16-19</b>	<b>20-23</b>	<b>24-27</b>
	<b>ITM 1-3%</b>		-				0.09	
			0.08***				(0.224)	
<b>Call</b>			(0.004)					
<b>Options</b>	<b>ITM 0-1%</b>	-	-0.02	-0.02				0.12
		0.05***	(0.208)	(0.206)				(0.238)
		(0.004)						

	<b>OTM 0-1%</b>	-0.00	-0.01	0.00	-	
		(0.932)	(0.518)	(0.735)	0.05***	
					(0.007)	
	<b>OTM 1-3%</b>	0.00	0.00	0.03***	-0.01	0.02
		(0.717)	(0.909)	(0.001)	(0.705)	(0.315)
	<b>ITM 1-3%</b>			0.01		
				(0.811)		
	<b>ITM 0-1%</b>	-0.03	-0.02	0.05*		
<b>Put</b>		(0.412)	(0.643)	(0.092)		
<b>Options</b>	<b>OTM 0-1%</b>	0.03**	0.00	0.00		0.08
		(0.026)	(0.824)	(0.948)		(0.341)
	<b>OTM 1-3%</b>	0.00	-0.01	-0.01		-0.03
		(0.727)	(0.252)	(0.267)		(0.230)

Series with a statistically insignificant p-value ( $> 0.1$ ) suggests that there is no difference in the spreads during the post-intervention period. In other words, no impact on the market quality can be observed due to the introduction of T/TH expirations. For example, a coefficient of -0.02 in 0-3 DTE and OTM 0-1% call options group in bid-ask spread suggests that, on average, the bid-ask spread for SPXW M/W/F expirations in that group decreased by \$0.02 post-intervention relative to the comparable SPY options. However, a p-value of 0.534 suggests that the decrease is statistically insignificant. In other words, we don't believe there is a change in bid-ask spread in this group between the pre- and post-intervention period.

Overall, the Exchange believes there is no market quality impact on the M/W/F expirations series due to the introduction of T/TH expirations. The majority of the series in the DnD regression results are statistically insignificant, which showed no impact on the spreads. While a slight increase in the bid-ask spread within the 24-27 DTE group has been observed, the Exchange believes it doesn't weaken the overall conclusion since these are the least active series with smaller volume.

While the Exchange's analysis does not prove that the observed improvements in the spreads could necessarily be attributed to the introduction of T/TH expirations instead of other market factors, the above regression results support the overall conclusion that the spreads in existing M/W/F series were not widening following the T/TH expirations.